

## Chapter 5: Water Quantity

### Section 5.1: Stream Flow

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## **GLOSSARY**

**100-year floodplain:** See Floodplain (100- and 500-year)

**500-year floodplain:** See Floodplain (100- and 500-year)

**50% Exceedance flows:** See Exceedance flows (50% & 90%)

**90% Exceedance flows:** See Exceedance flows (50% & 90%)

**Antecedent wetness index:** A measure of the decreasing influence of precipitation from previous days on current conditions.

**CFS:** The flow rate or discharge equal to one cubic foot (of water, usually) per second. This rate is equivalent to approximately 7.48 gallons per second. This is also referred to as a second-foot.

**Consumptive (water) use:** the loss of water from a ground- or surface- water source through a human-made conveyance system due to transpiration by vegetation, incorporation into products during their manufacture, evaporation, diversion, or any other process by which the water withdrawn is not returned to the waters of the basin undiminished in quantity.

**Correlation:** A relation existing between variables which tend to vary in a way not expected on the basis of chance alone.

**Discharge:** Flow rate of a stream or river.

**Exceedance flows (50% & 90%):** Flow exceedance, as used in this report, is an expression of the proportion of time that a specified mean monthly streamflow is equaled or exceeded during the period of record for a stream gage. The flow exceedance is presented here in terms of percentiles. The 50% flow is the flow that is equaled or exceeded in 50% of the months in the period of record. Hence, the 50% exceedance flow represents a median flow. The 90% flow is the flow that is equaled or exceeded in 90% of the months in the period of record. Hence, the 90% exceedance flow represents not the lowest flow seen at that location in a given month, but a very low flow.

**Half-life:** The time required for half the amount of a substance introduced into an ecosystem to be eliminated or disintegrated by natural processes.

**HSG:** See hydrologic soil group

**Hydrologic soil groups:** Soils grouped by characteristics that affect the rates of water infiltration and transmission (rate at which the water moves within the soil).

**Kendall's rank-order correlation:** A nonparametric method of determining an increasing or decreasing trend in a paired data set. Nonparametric statistical tests do not assume that the difference between the samples is normally distributed whereas parametric tests do. All tests involving ranked data, i.e. data that can be put in order, are nonparametric.

**Pacific Decadal Oscillation:** A climatic variability pattern common in the Pacific Northwest. Similar to the El Niño/Southern Oscillation (ENSO), except that Pacific Decadal Oscillation (or PDO) events typically persist for 20-to-30 year periods, while ENSO events typically persist for 6 to 18 months.

**PDO:** See Pacific Decadal Oscillation.

**Quaternary:** A unit of geologic time that began approximately 2 million years ago. We are currently in this period.

**$r^2$ :** A number between 0 and 1 which measures the degree to which two variables are linearly related. If there is perfect linear relationship, the correlation coefficient is 1; a value of 0 means that there is no linear relationship between the variables.

**Rank-order correlation:** See Kendall's rank-order correlation.

**Regression analysis:** Regression analysis is a statistical evaluation of a group of identifiable characteristics that together can predict the outcome of a specific event.

**Regulation:** With respect to streamflow, regulation refers to the degree that upstream runoff is controlled by human-made structures such as dams.

**Residual variation:** Unexplained (or residual) variation after fitting a regression model. It is the difference (or left over) between the observed value of the variable and the value suggested by the regression model.

**Significant:** In statistics the level of significance refers to the probability of rejecting the null hypothesis when the hypothesis is in fact true. (The null hypothesis represents a theory that has been put forward, either because it is believed to be true or because it is to be used as a basis for argument, but has not been proven. For example, in a clinical trial of a new drug, the null hypothesis might be that the new drug is no better, on average, than the current drug.) Usually, the significance level is chosen to be 0.05.

**Snowpack:** The total snow and ice on the ground, including both the new snow and the previous snow and ice that have not melted.

**UAR:** see unit-area runoff.

**Unit-area runoff:** Unit area runoff (UAR) is the stream flow normalized by contributing watershed area. For example, if the mean monthly discharge was 45 cfs at a stream gage having a watershed area of 100 mi<sup>2</sup>, the UAR would be  $45\text{cfs}/100\text{ mi}^2 = 0.45\text{ cfs}/\text{mi}^2$

**USGS:** United States Geological Survey. Agency within the Department of Interior responsible for, among other things, collecting and distributing streamflow data for the nation.

**WAU:** Watershed Administrative Unit. Administrative and planning units that encompass smaller areas within WRIAs. There are 828 WAUs within the state of Washington.

**WDNR:** Washington Department of Natural Resources.

**WRIA:** Water Resource Inventory Area. Administrative and planning units that encompass large river basins. There are 62 WRIAs within the state of Washington.



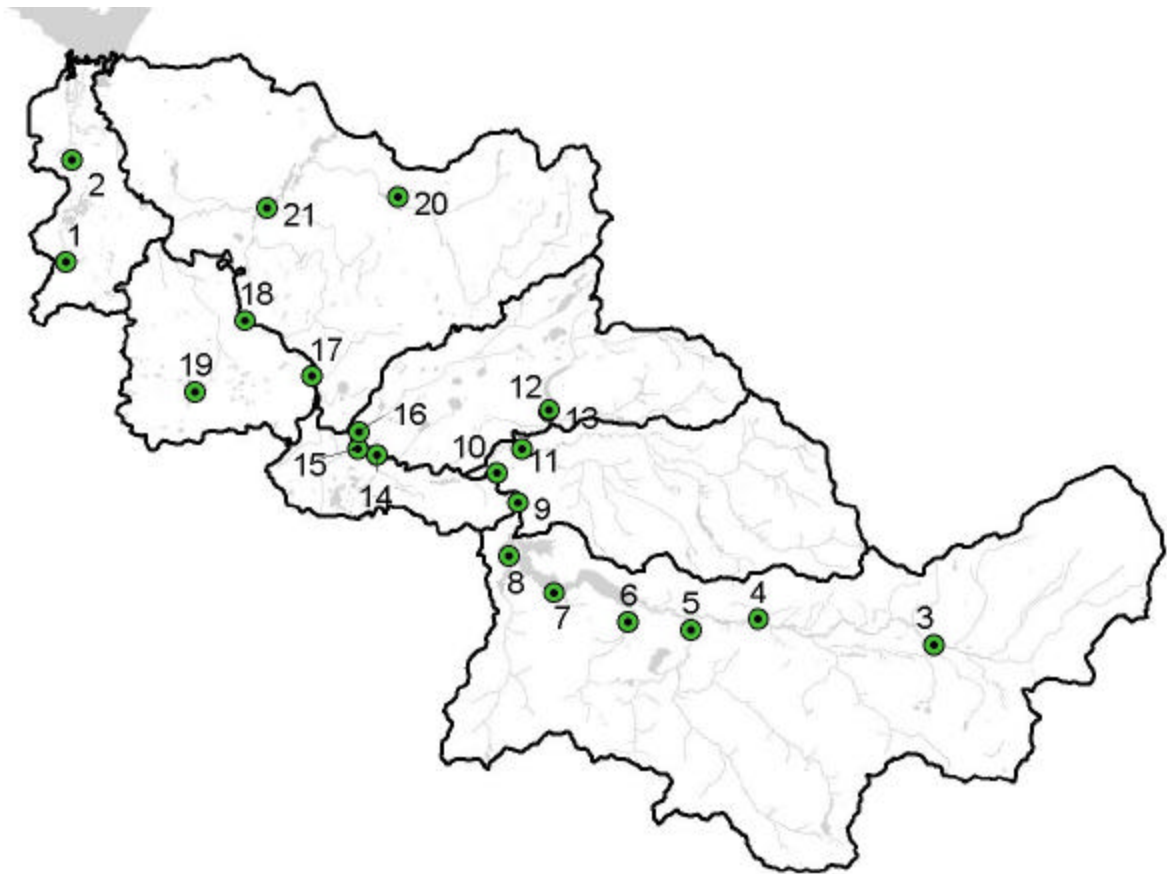


## **Chapter 5: Water Quantity**

### **Section 5.1: Stream Flow**

#### ***SUMMARY OF GAGING STATION DATA***

Twenty-one USGS stream gages are, or were, located within the Nisqually Basin (Figure 5.1-1, Table 5.1-1). Of these twenty-one gages, fifteen are located in the assessment area. Not all stream gages are currently active, and several contain records that are too short to be of any practical use. Additionally, several of the stations only have records for peak stream flows. Daily stream flow records are available from fifteen of the USGS stream gages in the Nisqually Basin (Figure 5.1-2, Table 5.1-1).



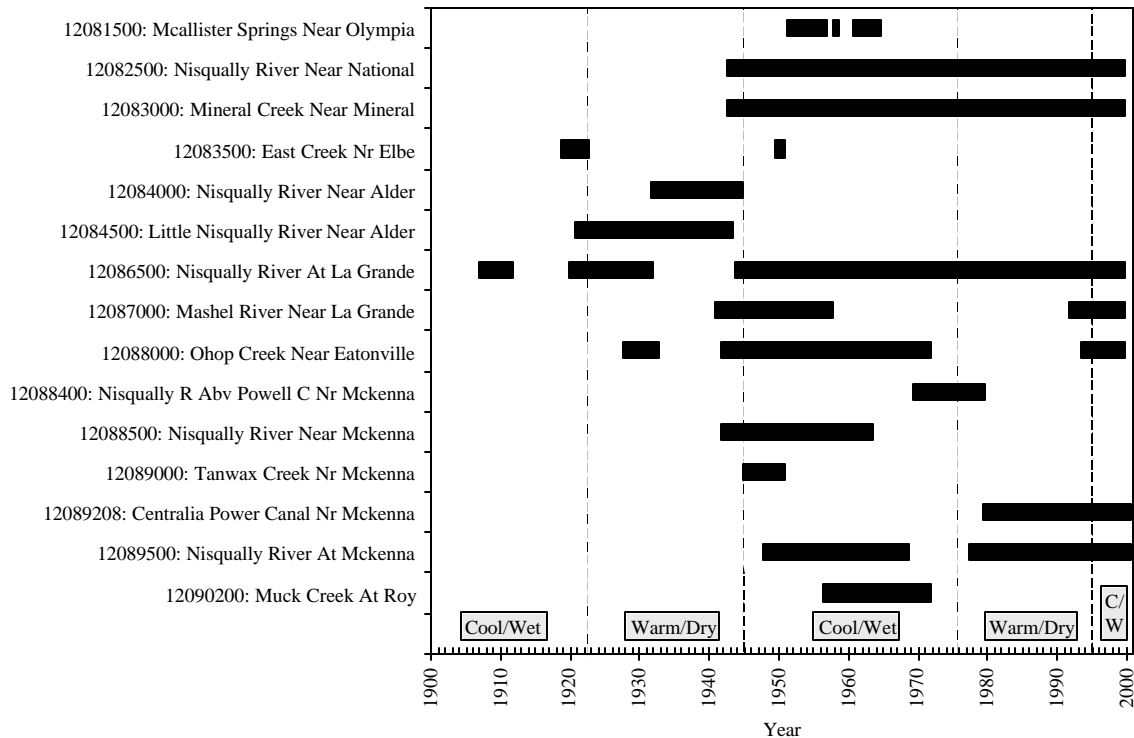
**Figure 5.1-1.** USGS stream gages in the Nisqually River Basin. Fish-bearing streams and water bodies are shown in gray. Data Sources: WDNR (1996) - subbasins (modified from WAU coverage), fish-bearing streams, water bodies, and WRIA boundaries; USGS (2001) - stream gage locations.

*Nisqually River Basin  
Level 1 Assessment*

**Table 5.1-1.** USGS stream gages in the Nisqually River Basin. Map number refers to Figure 5.1-1. Data Sources: USGS (2001), except where noted.

Map #	Sta. #	Station Name	Drain. Area (mi <sup>2</sup> )	Gage elev. (ft)	Period of Record		Degree & Type of Regulation **
					Peak flows *	Daily Streamflow	
1	1208-1300	Eaton Creek Near Yelm	2.28	175	1960-88	N/a	None: no regulations or diversions
2	1208-1500	McAllister Springs Near Olympia	n/a	<20	n/a	4/1/51 - 9/30/56 10/1/57 - 9/30/58 10/1/60 - 9/30/64	High: Gage pool regulated by low dam. City of Olympia diverted 1.7 - 10.8 cfs daily (mean 4.7 cfs), just above station. Occasional backwater from tides
3	1208-2000	Nisqually River Near Ashford	68.5	1,950	n/a	11/1910 - 9/1914	None: No upstream diversion or regulation
4	1208-2500	Nisqually River Near National	133	1,450	1943-99	6/1/42 - 9/30/99	Low: Flow effected by small diversions for domestic use; seasonally effected by significant snow or glacier melt water
5	1208-3000	Mineral Creek Near Mineral	75.2	1,340	1943-99	6/1/42 - 9/30/99	None: No regulation or diversion upstream from station
6	1208-3500	East Creek Nr Elbe	11.5	1,225	n/a	9/1/18 - 9/30/22 7/1/49 - 10/31/50	Low: No regulation, possibly some small diversion for domestic use.
7	1208-4000	Nisqually River Near Alder	252	1,013.9	1932-44	9/1/31 - 10/31/44	None: No upstream diversion or regulation
8	1208-4500	Little Nisqually River Near Alder	28	977.9	1921-43	8/1/20 - 5/31/43	Low: Flow effected by non-specific causes (small impoundments, check dams, ground water pumpage, etc).
9	1208-6000	Tacoma power conduit near La Grande	n/a	925	n/a	10/1919 - 9/1931	High: Flow regulated; conduit diverts water for City of Tacoma Power plant
10	1208-6500	Nisqually River At La Grande	292	490	1907-08 1910-11 1920-99	10/1/06 - 10/30/11 10/1/19 - 9/30/31 10/1/43 - 9/30/99	High (since 1943): Flow regulated by upstream reservoirs ***. All diversions returned to river upstream from gage.
11	1208-7000	Mashel River Near La Grande	80.7	619.53	1941-57 1992-99	10/1/40 - 9/30/57 10/1/91 - 9/30/99	Low: Small diversion for municipal supply for Eatonville. Some regulation at low water by millpond in Eatonville.
12	1208-7500	Lynch Creek Near Eatonville	16.3	550	n/a	6/1949 - 10/1949	Low: No known regulation. Some diversion for irrigation above station
13	1208-8000	Ohop Creek Near Eatonville	34.5	517.76	1928-32 1942-74 1993-99	6/1/27-9/30/32 9/1/41-10/2/71 6/22/93-9/30/99	Low: Flow affected by natural storage in Ohop Lake.
14	1208-8400	Nisqually R Abv Powell C Nr McKenna	431	388.94	1942-63 1970-79	3/1/69-9/30/79	High (since 1943): Flow regulated by upstream reservoirs ***. No upstream diversions
15	1208-8500	Nisqually River Near McKenna	445	373.6	1942-63	8/1/41 - 6/30/63	High (since 1943): Flow regulated by upstream reservoirs ***. Yelm Irrigation canal diverted up to 70 cfs during summer, 3.6 miles upstream, for use on lands downstream.
16	1208-9000	Tanwax Creek Nr McKenna	26	390	1945-50	12/1/44 - 9/30/50	None: No upstream diversion or regulation
17	1208-9208	Centralia Power Canal Nr McKenna	n/a	330	1993 1996-99	3/21/79-9/30/00	High: Flow regulated by headworks 500 ft upstream from station
18	1208-9500	Nisqually River At McKenna	517	285.47	1948-68 1978-99	10/1/47-9/30/68 5/24/77-9/30/00	High (since 1943): Flow regulated by upstream reservoirs ***. Centralia Power Canal diverts water 4.4 mi upstream from station, which is returned to river at power plant 9.2 mi downstream from station. Minor irrigation diversions upstream of station
19	1208-9700	Yelm Creek Nr Yelm	1.72	390	1968-76	N/a	None: No regulations or diversions
20	1209-0000	Muck Creek Near Loveland	16.9	410	n/a	7/1949 - 10/1949	Low: No regulations; small upstream diversion for domestic use
21	1209-0200	Muck Creek At Roy ****	86.8	310	1957-76 1996	6/1/56 - 9/30/71	Moderate: Some regulation in upstream lakes. Small amount of upstream diversion for domestic use.

Notes: \* Period of record is for water year  
 \*\* Information is from Sinclair and Pitz (1999), Zembrzski et al. (2001), and L.A. Fuste, USGS, personal comm., 5/3/01.  
 \*\*\* Flow regulated by City of Tacoma power plant at La Grande (at RM 42.5) since 12/43, by Alder Reservoir (at RM 44.2) since 11/44, and by La Grande Reservoir (at RM 42.5) since 2/45.  
 \*\*\*\* Pierce County Public Works and Utilities, Water Program, reactivated the Muck Creek gauge (and installed an additional gage on South Fork Muck Creek, at 8th Ave E, just inside Ft Lewis) in 2000 (Collins, J., pers. comm., 10/24/01). Data from these sites was not made available in time to be included in this report.



**Figure 5.1-2.** Timelines of the 15 USGS stream gages located within the Nisqually Basin that have mean daily flow data. Regional Pacific Decadal Oscillation (PDO) cycles are shown as vertical dashed lines. Refer to Figure 5.1-1 and Table 5.1-1 for gage locations.

## **STREAMFLOW ESTIMATES**

Estimates of streamflow were made for each subbasin, and for representative locations along the Nisqually River mainstem, using selected gage records. Caution should be used in interpreting these results, as they do not truly represent a “natural”, or pre European-settlement condition. All of the gages have had some degree of land-use change in their upstream contributing areas, and most have had some amount of water diversion during the period or record. Furthermore, the reaches along the Nisqually River mainstem are subject to significant regulation associated with the operation of the Alder/LaGrande and Centralia dams. Although it is not possible to quantify (at least at Level I) what these changes from a “natural” condition are, it seems reasonable to use estimated values derived from these gage records when assessing water availability under current conditions.

As can be seen in Figure 5.1-2, some of the stream flow gages in the Nisqually Basin are not currently active. The question might be asked whether or not a stream flow record that ended 35 years ago (e.g., gage # 12088500) is representative of current conditions. The use of this “old” data is valid providing that the conditions influencing stream flow have not changed significantly from the period of record to the present day. Among other factors, changes in precipitation patterns can affect the usefulness of older flow data. As discussed in greater detail in Chapter 2.0, the principal factor that we need to consider when examining long-term precipitation patterns is the Pacific Decadal Oscillation, or PDO. The PDO consists of warm/dry and cold/wet phases that persist for 20-to-30 year periods. The five distinct PDO cycles that have occurred since 1900 are shown in Figure 5.1-2. When considering the validity of a particular gage record to be used to represent current conditions it is important to compare the proportion of the record that falls within these warm/dry and cold/wet PDO phases.

An additional factor to consider when evaluating the appropriateness of a particular gage record for representing current conditions is how have land use patterns changed over the period of record. Changes in land use may directly affect runoff through changes in watershed parameters affecting runoff (e.g., impermeable area associated with certain land uses, changes in vegetation patterns), as well as indirectly through the variable water demand associated with different water uses. No effort was made to evaluate how changes in land uses may have changed runoff characteristics as part of this Level I assessment. The mechanisms for change are, however, addressed in Chapter 6.0.

## **SELECTION OF REPRESENTATIVE GAGES**

Stream gage records used to represent specific subbasins and mainstem Nisqually River reaches are provided in Table 5.1-2. Also provided in Table 5.1-2 are PDO cycles associated with the period of record used from each gage. Table 5.1-3 provides additional subbasin characteristics considered when selecting representative gage records. A discussion of why specific subbasins were selected is provided below.

**Table 5.1-2.** Stream gages used to represent specific subbasins and/or mainstem Nisqually River reaches.

USGS gage	PDO Cycles		Subbasin(s) or mainstem reach this gage represents
	Cool/wet	Warm/dry	
12081500: McAllister Springs Nr. Olympia	100%	0%	1. McAllister
12090200: Muck Creek at Roy	100%	0%	2. Muck/Murray 3. Yelm
12088000: Ohop Creek near Eatonville	68%	32%	4. Toboton/Powell/Lackamas 5. Tanwax/Kreger/Ohop
12087000: Mashel River near La Grande	58%	42%	6. Mashel
12088400: Nisqually R Above Powell C Nr McKenna	74%	26%	7. Mainstem (upper)
12089500: Nisqually River At McKenna	58%	42%	7. Mainstem (middle)
12089208: Centralia Power Canal Nr McKenna, and 12089500: Nisqually River At McKenna (combined)	22%	78%	7. Mainstem (lower)

**Table 5.1-3.** Subbasin characteristics considered when selecting representative stream gages.

Subbasin	Quaternary sediments (% area )	Percent subbasin area in HSG* A&B	Mean subbasin slope	Mean annual precipitation (in.)
1. McAllister	99%	57%	9%	45
2. Muck/Murray	100%	n/a	5%	42
3. Yelm	99%	39%	6%	43
4. Toboton/Powell/Lackamas	65%	7%	19%	38
5. Tanwax/Kreger/Ohop	64%	n/a	16%	46
6. Mashel	37%	n/a	31%	71

Note: \* = hydrologic soil group; see Chapter 2 for further discussion.

## Subbasins

The McAllister Springs gage (#12081500) was used to represent stream flow conditions in the McAllister subbasin (Table 5.1-2). The gage is located at the upstream end of the mainstem reach (Figure 5.1-1), approximately 5 miles upstream from the outlet of the subbasin. The entire period of record coincides with a cool/wet PDO cycle (Table 5.1-2); consequently streamflow statistics calculated using this gage record might overestimate average conditions (i.e., the average flow for a given month will be predicted as being higher than it would have been had the proportion of cool/wet and

warm/dry years been the same). Flows at the McAllister Springs gage are highly regulated by the City of Olympia's water withdrawals (Table 5.1-1). No major dam storage occurs in the subbasin.

The Muck Creek at Roy gage (#12090200) was used to represent streamflow conditions in the Muck/Murray subbasin (Table 5.1-2). The gage is located near the town of Roy, approximately 6 miles upstream from the outlet of Muck Creek (Figure 5.1-1). The portion of Muck Creek downstream of the gage cuts through the glacial deposits located within the area, and picks up considerable spring flow. Consequently, this gage may not adequately represent conditions in the lower portions of Muck Creek. The entire period of record coincides with a cool/wet PDO cycle; consequently, streamflow statistics calculated using this gage record might overestimate average conditions (i.e., the average flow for a given month will be predicted as being higher than it would have been had the proportion of cool/wet and warm/dry years been the same). No stream flow records are available for the Yelm subbasin; hence the Muck Creek gage was also used to represent streamflow conditions in the Yelm subbasin. The Muck Creek gage was chosen because the Muck/Murray and Yelm subbasins are similar with respect to the proportion of the basin made up of Quaternary sediments, mean basin slope, and mean annual precipitation (Table 5.1-3). Hydrologic soil group (HSG) characteristics are not available for the Muck/Murray subbasin (see Chapter 2 for further discussion of HSGs), however, given the similarities in the underlying geology between the Muck/Murray and Yelm subbasins the HSG characteristics are probably similar. Flows at the Muck Creek gage are only moderately regulated due to the minor dam storage that occurs in the subbasin.

The Ohop Creek gage (#12088000) was used to represent streamflow conditions in the Tanwax/Kreger/Ohop subbasin (Table 5.1-2). The gage is located approximately 6 miles upstream from the outlet of Ohop Creek (Figure 5.1-1). The gage is located downstream of all major tributaries. Approximately 2/3 of the period of record coincides with a cool/wet PDO cycle and the remainder coincides with a warm/dry cycle. Consequently, streamflow statistics calculated using this gage record should approximate average conditions. No stream flow records are available for the Toboton/Powell/Lackamas subbasin; hence, the Ohop Creek gage was also used to represent streamflow conditions in the Toboton/Powell/Lackamas subbasin. The Ohop Creek gage was chosen because the Tanwax/Kreger/Ohop and Toboton/Powell/Lackamas subbasins are similar with respect to the proportion of the basin made up of quaternary sediments and mean basin slope (Table 5.1-3). Hydrologic soil group characteristics are not available for the entire Tanwax/Kreger/Ohop subbasin; however, given the similarities in the underlying geology between the Tanwax/Kreger/Ohop and Toboton/Powell/Lackamas subbasins the

HSG characteristics are probably similar. Mean annual precipitation in the Toboton/Powell/Lackamas subbasin is approximately  $\frac{3}{4}$  of what occurs in the Tanwax/Kreger/Ohop subbasin; consequently streamflow statistics calculated using the Ohop Creek gage may be overestimated. Flows at the Ohop Creek gage are not regulated and only natural storage occurs in Ohop Lake.

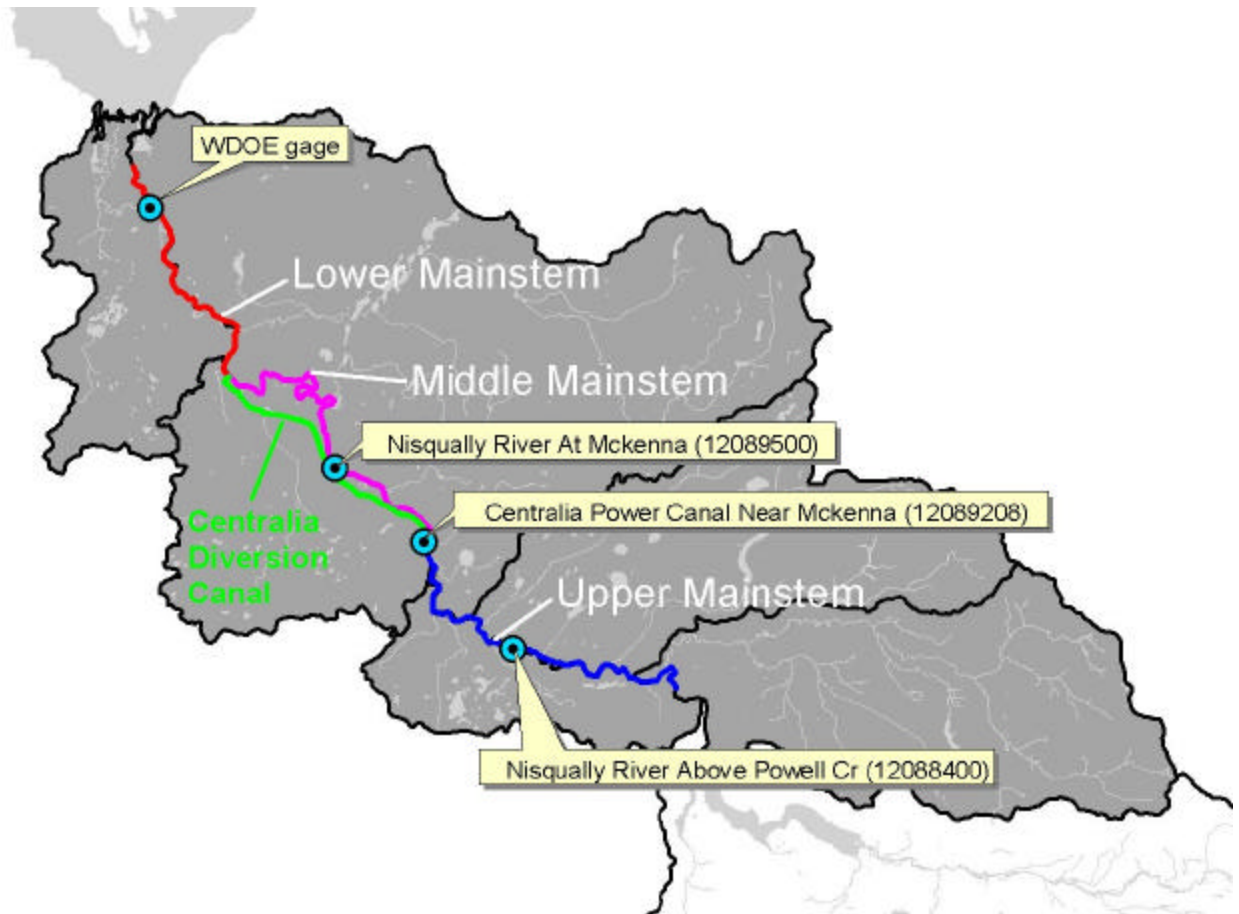
The Mashel River gage (#12087000) was used to represent streamflow conditions in the Mashel subbasin. The gage is located approximately 3 miles upstream from the outlet of the subbasin (Figure 5.1-1), and is located downstream of all major tributaries. Approximately  $\frac{1}{2}$  of the period of record coincides with a cool/wet PDO cycle and the remainder coincides with a warm/dry cycle. Consequently, streamflow statistics calculated using this gage record should approximate “normal” conditions. Flows at the Mashel River gage are not regulated and only minor dam storage occurs.

## **Mainstem Nisqually River Reaches**

Streamflow estimates were made for three reaches along the Nisqually River mainstem (Table 5.1-2; Figure 5.1-3). The downstream end of each reach roughly corresponds to the three instream flow control points established for the Nisqually River mainstem (Chapter 5.3).

Streamflow estimates for the Upper Reach were made using data from USGS gage # 12088400 - Nisqually River Above Powell Creek (Table 5.1-2). The gage is located approximately 7 miles upstream of the reach outlet. Powell, Toboton, Lackamas, and Tanwax Creeks join the Nisqually River downstream of the gage. Approximately  $\frac{3}{4}$  of the period of record coincides with a cool/wet PDO cycle and the remainder coincides with a warm/dry cycle. Consequently, streamflow statistics calculated using this gage record might be somewhat above average conditions. Flows at the gage are regulated by upstream reservoirs.

Streamflow estimates for the Middle Reach were made using data from USGS gage #12089500 - Nisqually River At McKenna (Table 5.1-2). The gage is located approximately in the middle of the reach. Yelm and Murray Creeks join the Nisqually River downstream of the gage. Approximately  $\frac{1}{2}$  of the period of record coincides with a cool/wet PDO cycle and the remainder coincides with a warm/dry cycle; consequently, streamflow statistics calculated using this gage record should be close to average conditions. Flows at the gage are regulated by upstream reservoirs and Centralia’s diversion dam.

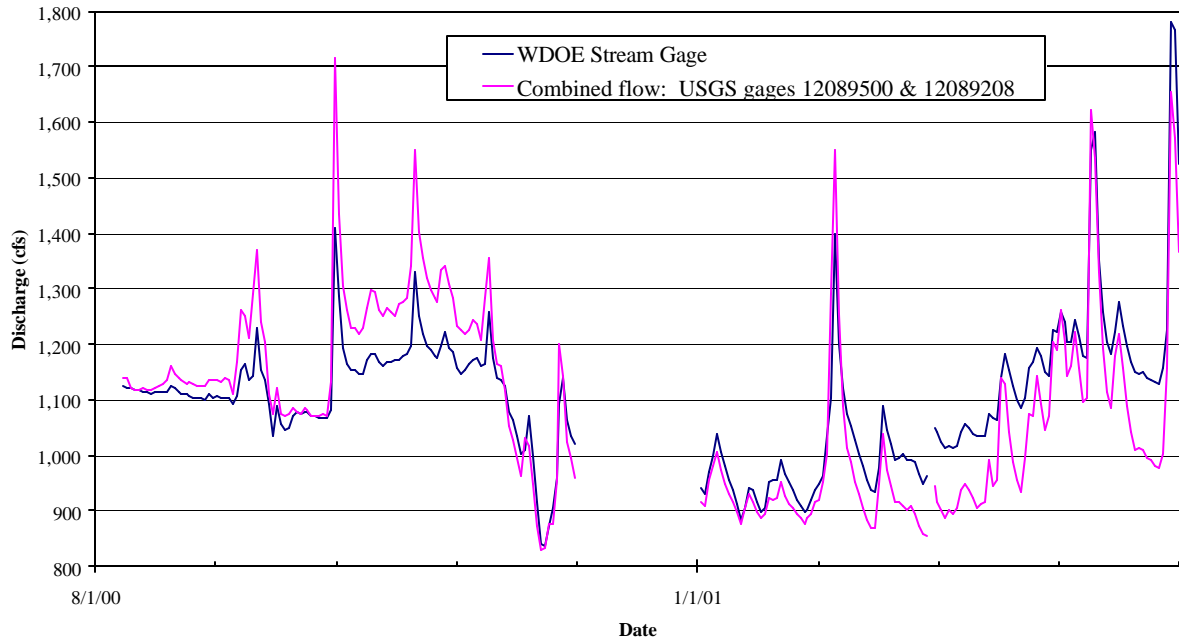


**Figure 5.1-3.** Mainstem Nisqually River streamflow reaches. Also shown are locations of stream gages used to estimate streamflow (blue circles), and Centralia diversion canal.

Streamflow estimates for the Lower Reach were made using the combined flow data from USGS gages # 12089500 - Nisqually River At McKenna and #12089208 - Centralia Power Canal Nr McKenna (Table 5.1-2). The gages are located upstream of the reach and Muck Creek joins the Nisqually River downstream of the gage. The location of the gage upstream of the reach may introduce considerable error into the streamflow estimates. However, recent (and very short-term) data collected by the WDOE at river mile 4.6 (T. Culhane, WDOE, personal comm., 5/11/01) suggests that streamflow is greater near the downstream end of the Lower Reach in some months (i.e., that tributary and spring flow makes a significant contribution within the reach), while in other months the Lower Reach is a “losing” reach (Figure 5.1-4). These data are in contrast to AGI Technologies’ (1999) conclusion that this reach is a net groundwater discharge reach. A correct understanding of surface/groundwater interactions in the Lower Reach is an



existing data gap that should be further investigated. A better understanding of the true nature of this interaction should include (but not be limited to) longer-term measurements at the WDOE gage site.



**Figure 5.1-4.** Comparison of discharge measurements at the WDOE study site at RM 4.6, and the combined flow of USGS gages 12089500 and 12089208.

Approximately  $\frac{1}{4}$  of the period of record for the combined flow data from USGS gages # 12089500 and #12089208 coincides with a cool/wet PDO cycle and the remainder coincides with a warm/dry cycle (Table 5.1-2). Consequently, streamflow statistics calculated using this gage record might be somewhat below “normal” conditions. Flows at the gage are regulated by upstream reservoirs.

## SUMMARY STATISTICS

Summary statistics are presented below showing the amount of surface water present by month in median and low streamflow years. The 50- and 90-percent exceedance values were used to represent the median and low flows respectively<sup>1</sup>. Monthly exceedance flows were first calculated for each of the representative gages identified above (Table 5.1-2) using mean daily flow values. The methods used to extrapolate from

<sup>1</sup> Flows are larger than the 50% exceedance flow 50% of the time. Hence, the 50% exceedance flow represents a median flow. Flows are larger than the 90% exceedance flow 90% of the time. Hence, the 90% exceedance flow represents not the lowest flow seen in the basin, but a very low flow.

gage records to subbasins and reaches varied slightly, consequently, results are presented in three sections below.

### **McAllister Subbasin**

The USGS has not defined a drainage area contributing to the McAllister Creek gage due to the complex geology and groundwater dynamics in the area. Consequently, it is not possible to define a unit-area runoff for the gage record. AGI Technologies (1999) summarized additional data available from a variety of studies on all sources contributing to average annual discharge at the subbasin outlet (Table 5.1-4). These data indicate that, on an annual basis, the streamflow at the subbasin outlet is 2.6 times the discharge at the McAllister Springs gage (i.e., 62 cfs / 24 cfs = 2.6; Table 5.1-4). This same relationship was applied to the monthly 50- and 90% exceedance flows calculated from the gage record. Results for the basin outlet are presented in (Table 5.1-5) and displayed graphically in (Figure 5.1-5).

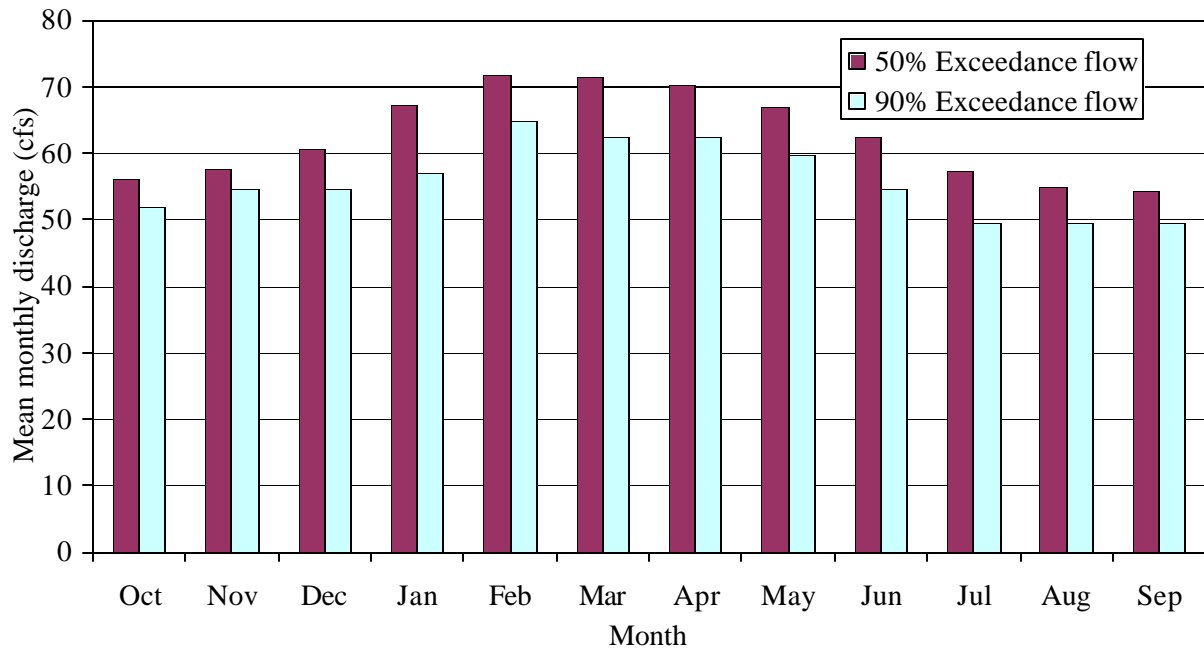
**Table 5.1-4.** Annual contribution to McAllister Creek at I-5 Bridge (from AGI Technologies, 1999).

Contributing source	Contributing discharge (cfs)
McAllister gage (12081500)	24 *
Abbott Springs	5 to 7
Wetlands Seepage	17
Medicine Creek	0.5
Little McAllister Ck	4
Valley side springs	10.5
<b>Total @ I-5 bridge</b>	<b>62</b>

\* The discharge at the McAllister gage does not include City of Olympia water withdrawals

**Table 5.1-5.** Estimated flow exceedance values for the McAllister Creek subbasin.

Month	50% Exceedance flow (cfs)		90% Exceedance flow (cfs)	
	@ McAllister gage	@ Subbasin outlet	@ McAllister gage	@ Subbasin outlet
Oct	22	<b>56</b>	20	<b>52</b>
Nov	22	<b>58</b>	21	<b>55</b>
Dec	23	<b>61</b>	21	<b>55</b>
Jan	26	<b>67</b>	22	<b>57</b>
Feb	28	<b>72</b>	25	<b>65</b>
Mar	28	<b>72</b>	24	<b>62</b>
Apr	27	<b>70</b>	24	<b>62</b>
May	26	<b>67</b>	23	<b>60</b>
Jun	24	<b>63</b>	21	<b>55</b>
Jul	22	<b>57</b>	19	<b>49</b>
Aug	21	<b>55</b>	19	<b>49</b>
Sep	21	<b>54</b>	19	<b>49</b>



**Figure 5.1-5.** Estimated flow exceedance values for the McAllister Creek subbasin.

## **Other Subbasins**

For the remainder of the subbasins a unit-area runoff approach was used to estimate monthly values of the 50- and 90% exceedance flows at the subbasin “outlet”<sup>2</sup>. Unit-area runoff (UAR)<sup>3</sup> values were first calculated for the stream gages used to represent specific subbasins. Unit-area runoff values were then multiplied by the subbasin area to arrive at monthly estimates of exceedance flows. Results are presented in Table 5.1-6 and displayed graphically in Figure 5.1-6.

## **Mainstem Nisqually River**

Monthly estimates of the 50- and 90% exceedance flows for the three Nisqually River mainstem reaches were made using the representative gage records; no unit-area adjustments were made. Results are presented in Table 5.1-7 and displayed graphically in Figure 5.1-7. It is interesting to note that in most months the estimated flows are actually higher at the Upper Reach than the Lower Reach. This may be due to a number of reasons including different periods of record used for different locations, and corresponding differences in PDO cycles, discharge of surface water from the Nisqually River to groundwater, consumptive water uses, leakage (without return flow) from the Centralia Canal, or error in discharge measurements at the gage stations. The available data is not sufficient to determine which, if any, of these reasons are responsible for the observed downstream decrease in values.

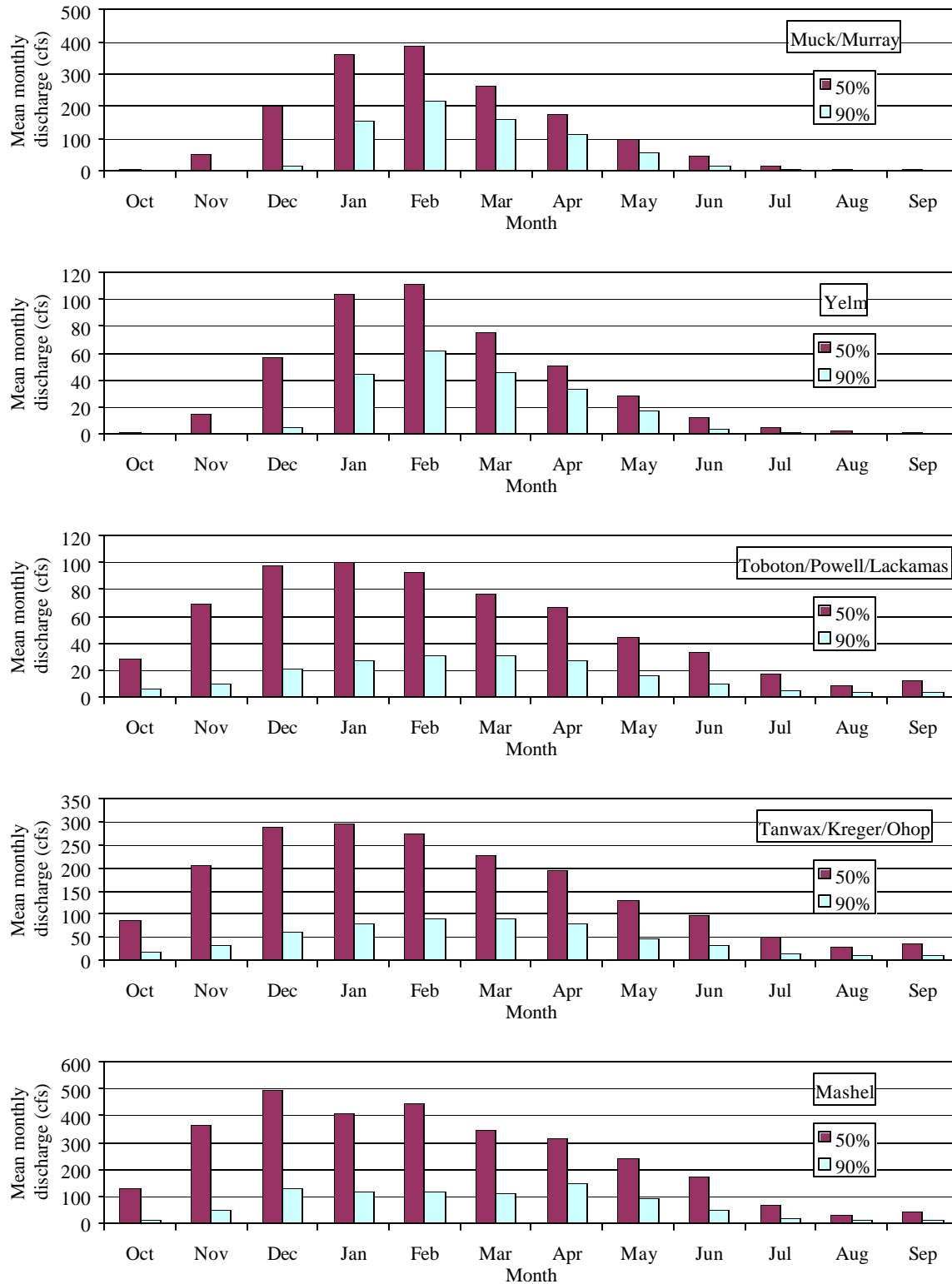
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<sup>2</sup> Note that the subbasins, as defined by the TAC, are not true “watersheds”, i.e., all of the subbasin area does not drain to a single outlet point. For example, the Muck Creek watershed is approximately 92 square miles in size, however the Muck/Murray subbasin is approximately 182 square miles in size, containing the Murray Creek drainage, and additional areas that drain directly to the Nisqually River.

<sup>3</sup> Unit area runoff (UAR) is the stream flow normalized by contributing watershed area. For example, if the mean monthly discharge was 45 cfs at a stream gage having a watershed area of 100 mi<sup>2</sup>, the UAR would be  $45\text{cfs}/100\text{ mi}^2 = 0.45\text{ cfs}/\text{mi}^2$

**Table 5.1-6.** Estimated flow exceedance values (50- and 90%) for the Muck/Murray, Yelm, Toboton/Powell/Lackamas, Tanwax/Kreger/Ohop, and Mashel subbasins. Unit-area runoff (UAR; CFS/square mile) values are calculated from representative gage stations (see Table 5.1-2); Subbasin values (CFS) are estimated flows at subbasin “outlet”.

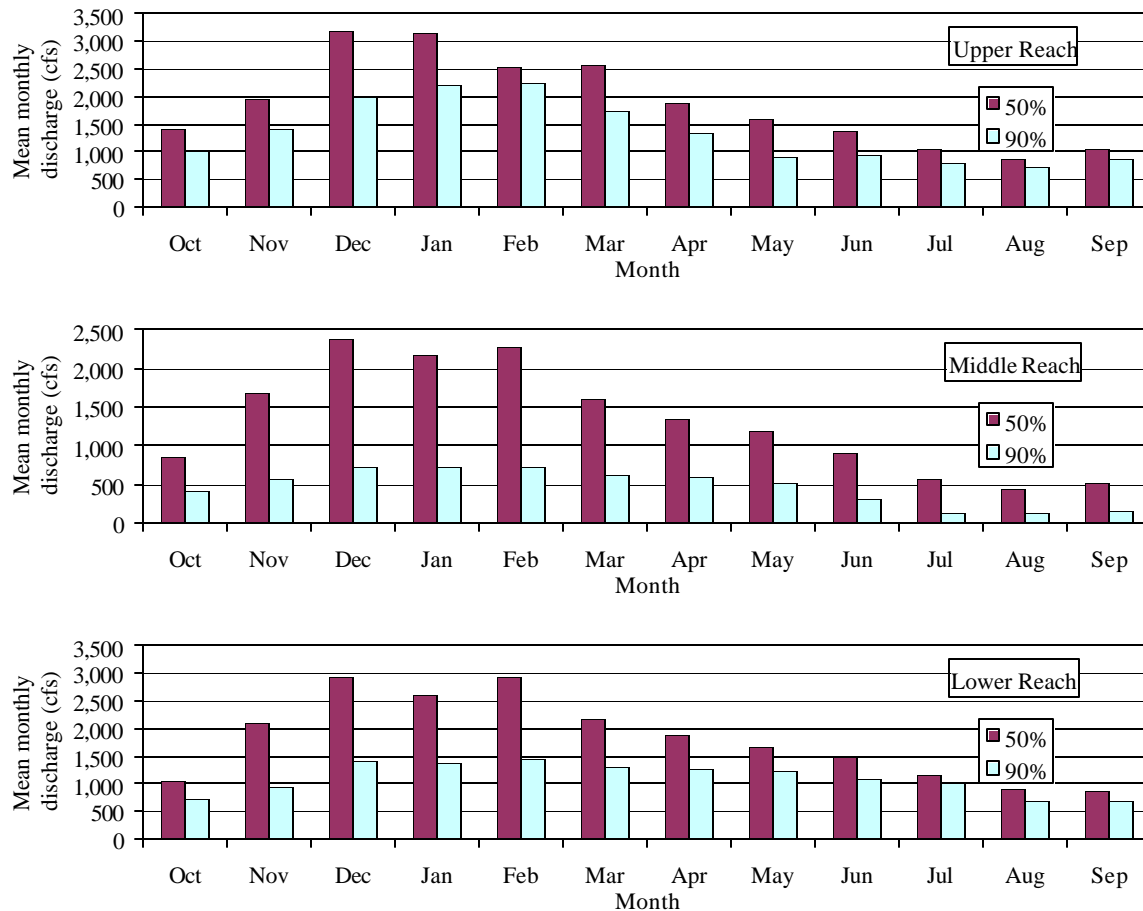
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Muck/ Murray	50%	UAR	0.02	0.28	1.10	2.00	2.14	1.47	0.98	0.54	0.25	0.09	0.04	0.01
		Subbasin	3	50	200	362	389	266	177	99	44	16	7	3
	90%	UAR	0.00	0.00	0.08	0.86	1.20	0.89	0.63	0.32	0.08	0.02	0.00	0.00
		Subbasin	0	0	15	157	217	161	115	59	15	3	1	0
Yelm	50%	UAR	0.02	0.28	1.10	2.00	2.14	1.47	0.98	0.54	0.25	0.09	0.04	0.01
		Subbasin	1	14	57	104	111	76	51	28	13	5	2	1
	90%	UAR	0.00	0.00	0.08	0.86	1.20	0.89	0.63	0.32	0.08	0.02	0.00	0.00
		Subbasin	0	0	4	45	62	46	33	17	4	1	0	0
Toboton/ Powell/ Lackamas	50%	UAR	1.04	2.49	3.53	3.60	3.37	2.78	2.40	1.60	1.20	0.60	0.33	0.45
		Subbasin	29	69	98	100	94	77	67	45	33	17	9	13
	90%	UAR	0.21	0.38	0.75	0.99	1.10	1.10	0.99	0.58	0.38	0.19	0.12	0.14
		Subbasin	6	10	21	27	31	31	27	16	10	5	3	4
Tanwax/ Kreger/ Ohop	50%	UAR	1.04	2.49	3.53	3.60	3.37	2.78	2.40	1.60	1.20	0.60	0.33	0.45
		Subbasin	86	205	290	295	277	228	197	132	99	49	27	37
	90%	UAR	0.21	0.38	0.75	0.99	1.10	1.10	0.99	0.58	0.38	0.19	0.12	0.14
		Subbasin	17	31	62	81	90	90	81	48	31	16	10	12
Mashel	50%	UAR	1.46	4.07	5.53	4.59	5.02	3.87	3.52	2.72	1.93	0.78	0.32	0.45
		Subbasin	130	363	494	410	447	346	314	243	172	69	28	40
	90%	UAR	0.15	0.55	1.46	1.31	1.35	1.24	1.67	1.04	0.58	0.21	0.14	0.12
		Subbasin	13	49	130	117	120	111	149	93	52	19	12	11



**Figure 5.1-6.** Estimated flow exceedance values (50- and 90%) for the Muck/ Murray, Yelm, Toboton/ Powell/ Lackamas, Tanwax/ Kreger/ Ohop, and Mashel subbasins.

**Table 5.1-7.** Estimated flow exceedance values (50- and 90%) for the three mainstem Nisqually River reaches (refer to Figure 5.1-3 for reach locations). All values in CFS. See Table 5.1-2 for gages used.

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Upper reach	50%	1,399	1,942	3,191	3,149	2,521	2,580	1,864	1,598	1,364	1,030	862	1,038
	90%	997	1,420	2,000	2,190	2,230	1,740	1,330	900	930	800	718	874
Middle reach	50%	841	1,687	2,377	2,180	2,265	1,614	1,351	1,177	913	574	438	525
	90%	403	556	732	728	711	622	600	521	297	135	117	163
Lower reach	50%	1,064	2,080	2,947	2,624	2,941	2,180	1,887	1,652	1,468	1,158	908	868
	90%	739	951	1,399	1,367	1,457	1,306	1,259	1,220	1,097	1,006	700	682



**Figure 5.1-7.** Estimated flow exceedance values (50- and 90%) for the mainstem Nisqually River reaches.

## **CONFIDENCE IN STREAMFLOW ESTIMATES**

One of the constraints in completing this level I assessment was to limit any analysis to available data resources. Consequently, this assessment of streamflow relied solely on the analysis of available stream flow records from the lower Nisqually Basin. Relative to other watersheds in the region the lower Nisqually Basin has a fairly well distributed network of gages; most subbasins and mainstem reaches having at least one gage with ten or more years of data. However, the confidence in the results presented above is limited by the following:

- For several of the representative gages used in this assessment the proportion of data was heavily weighted to cool/wet PDO phases. The result of this would be to overestimate average stream flow conditions (i.e., the average flow for a given month will be predicted as being higher than it would have been had the proportion of cool/wet and warm/dry years been the same).
- No stream gages are located within either the Toboton/Powell/Lackamas or Yelm subbasins. The lack of a gage in the Toboton/Powell/Lackamas subbasin is a particular problem because the mean annual precipitation in the Toboton/Powell/Lackamas subbasin is approximately  $\frac{3}{4}$  of what occurs in the Tanwax/Kreger/Ohop subbasin, consequently streamflow statistics calculated using the Ohop Creek gage may have overestimated stream flows in the Toboton/Powell/Lackamas subbasin.
- Stream flow records are available for only a very short period at the downstream end of the Nisqually River lower reach. Furthermore, the limited records that are available suggest that the surface/groundwater interactions in this reach need further investigation.
- No attempt was made to factor in possible impacts to stream flows from changing land use patterns over the period of record.

Potential future actions to increase the confidence in stream flow estimates could include: 1) maintaining existing stream gages in the area, 2) reactivating discontinued stations, 3) installing gages in the Yelm and Toboton/Powell/Lackamas subbasins, 4) making the gage that is located at the downstream end of the lower Nisqually River reach a permanent station, 5) further examining the surface/groundwater interaction in the lower Nisqually River reach, 6) developing a stream flow model for the basin that incorporates changes in land use patterns. These are discussed in Chapter 7.0.



## **STREAMFLOW TREND ANALYSIS**

The purpose of this portion of the assessment was to evaluate trends over time for both mean annual and annual low flows in the lower Nisqually Basin. Two approaches were used. First, trends were investigated in the streamflow variables themselves. Secondly, trends were investigated in the residual variation after the influence of precipitation had been factored out.

Two stream gages were selected for this analysis; one gage to represent conditions in the tributary streams, and the second to represent conditions in the mainstem Nisqually River. The Ohop Creek gage (#12088000) was selected as the representative tributary gage because it has the longest period of record of any tributary gage in the lower Nisqually river basin. The combined flow of the Nisqually River near McKenna and Centralia Power Canal near McKenna (gages #12088500 and #12089208) were selected for analysis because the combined flow of these two gages provides the best available representation of conditions closest to the mouth of the river.

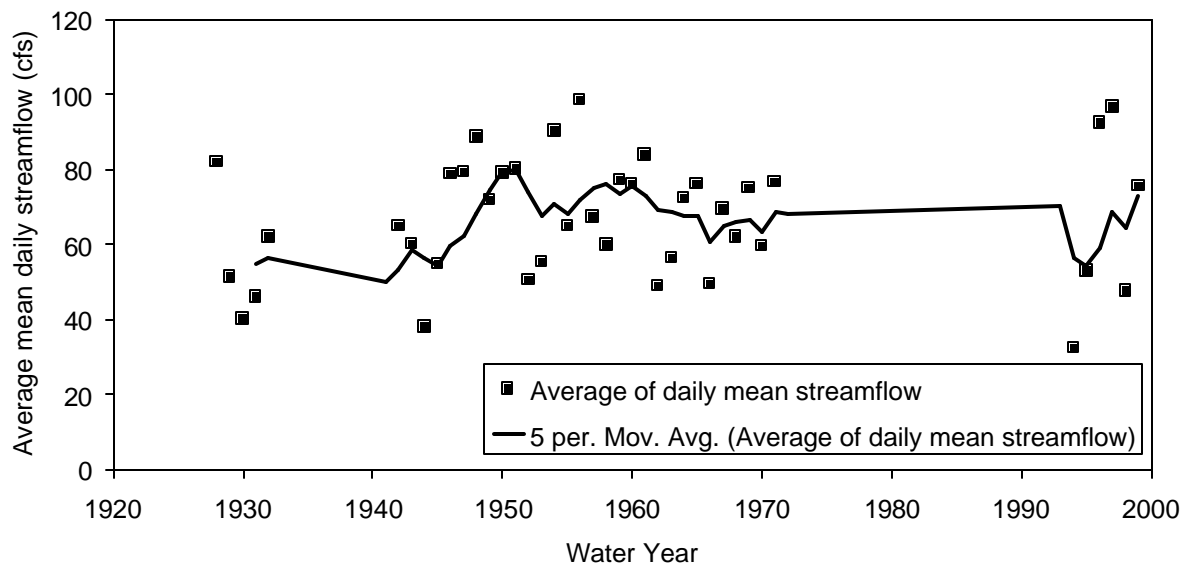
## **STREAMFLOW TREND ANALYSIS**

A statistical trend analysis was performed to determine if significant time-trends exist for mean annual flow, and annual low flow, at each of the two representative locations. Kendall's rank-order correlation (Kendall and Gibbons, 1990) was used to test for trends over time. Kendall's test is a non-parametric method of determining an increasing or decreasing trend in a paired data set. Values of the trend coefficient range from  $-1.0$ , which indicates a perfect inverse correlation, to  $1.0$ , which indicates a perfect positive correlation. For this analysis, significance was defined at the  $p < 0.05$  level.

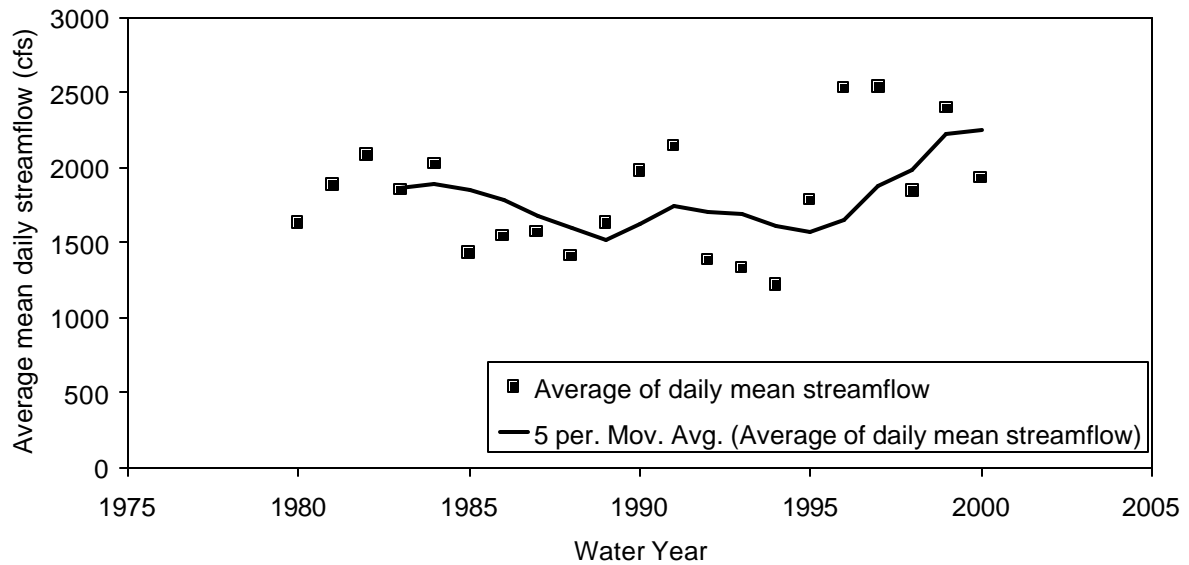
Mean annual flow showed no significant trends over the period of record at either the Ohop Creek gage (Table 5.1-8, Figure 5.1-8) or for the combined flows of the Nisqually River and Centralia Canal location (Table 5.1-8, Figure 5.1-9). This suggests there is no long-term trend (either decreasing or increasing) in flows. The primary limitation in this analysis is the discontinuity in the Ohop Creek gage data set, and the relatively short period of record for the combined flows of the Nisqually River and Centralia Canal location

**Table 5.1-8.** Summary of trend analysis results.

Streamflow variable	Period of record (water year)	Trend coefficient	Significance
Mean annual flow: Ohop gage	1928-32 1942-71 1994-99	0.0610	0.5744
Mean annual flow: Combined flow Nisqually & Centralia Canal	1980-2000	0.1048	0.5065
Annual low flow: Ohop gage	1927-32 1942-71 1993-99	-0.0045	0.9666
Annual low flow: Combined flow Nisqually & Centralia Canal	1979-2000	0.1215	0.4296

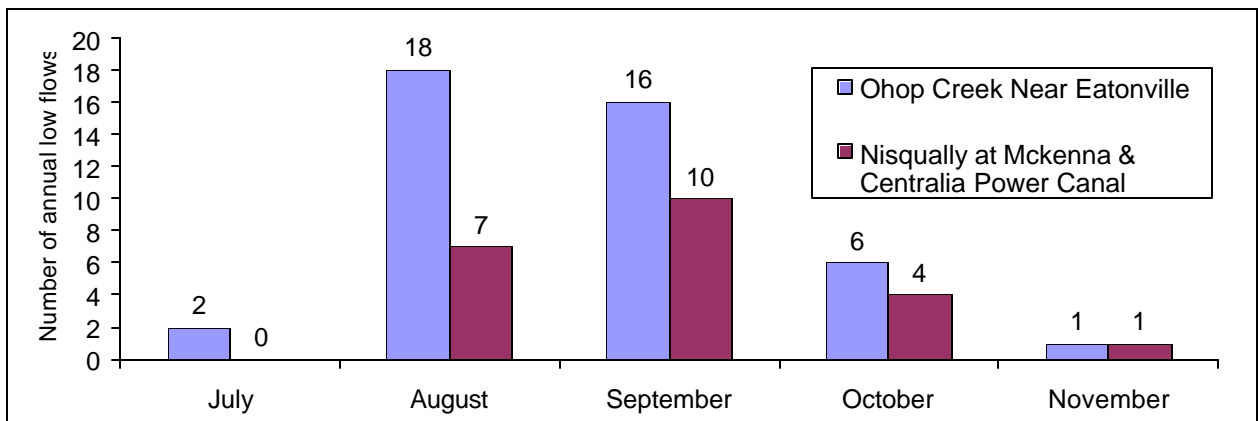


**Figure 5.1-8.** Mean annual flow, Ohop Creek stream gage.

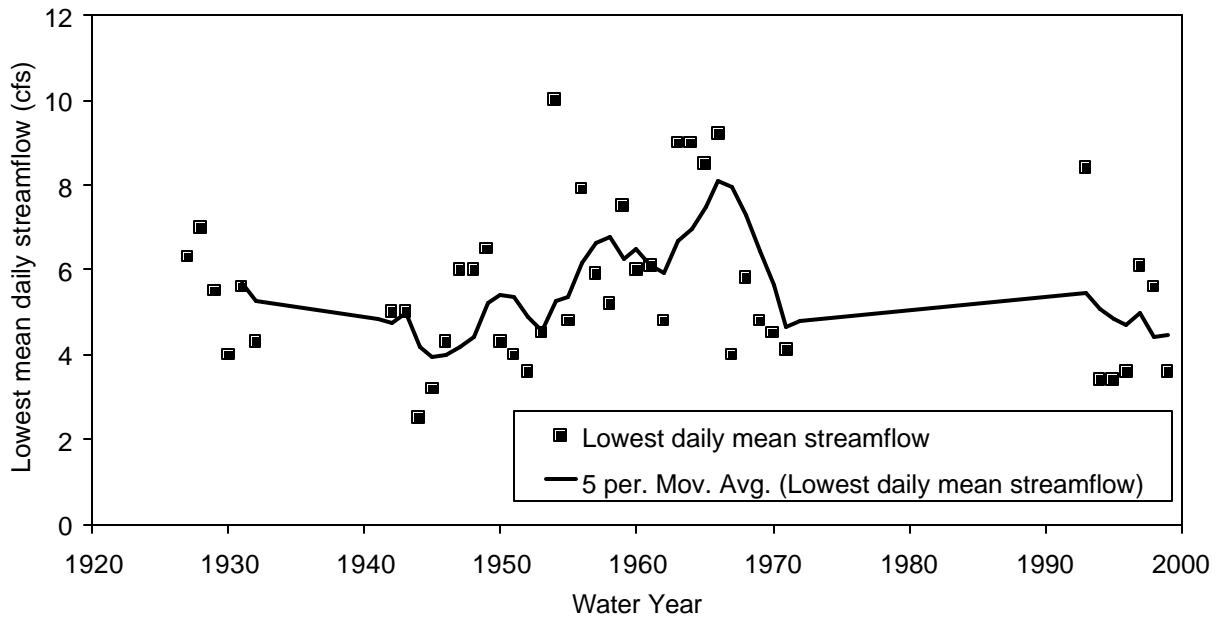


**Figure 5.1-9.** Mean annual flow for the combined records of the Nisqually River at McKenna and Centralia Power Canal gages.

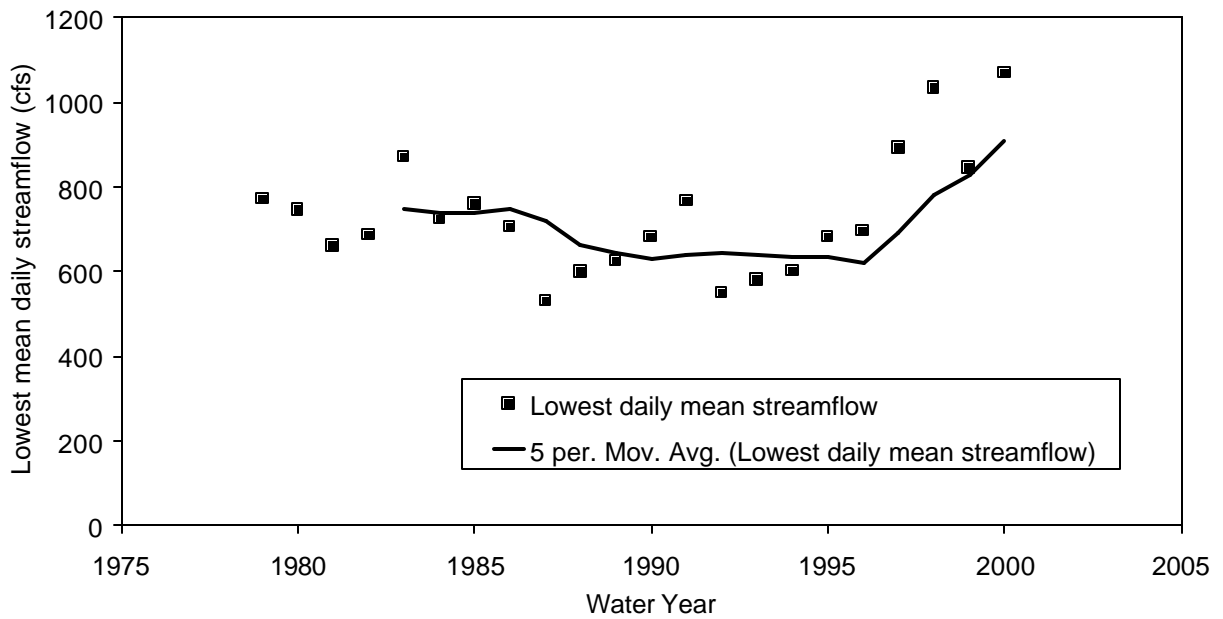
Annual low flows occur primarily in the months of August and September at both the Ohop Creek gage and for the combined flows of the Nisqually River and Centralia Canal location (Figure 5.1-10). Annual low flows also showed no significant trends (Table 5.1-8) over the period of record at either the Ohop Creek gage (Figure 5.1-11) or for the combined flows of the Nisqually River and Centralia Canal location (Figure 5.1-12).



**Figure 5.1-10.** Frequency of annual low flows by month for the Ohop Creek gage and for the combined flows of the Nisqually River and Centralia Canal location.



**Figure 5.1-11.** Annual low flows, Ohop Creek stream gage.



**Figure 5.1-12.** Annual low flows for the combined records of the Nisqually River at McKenna and Centralia Power Canal gages.

## **RESIDUAL VARIATION TREND ANALYSIS**

Regression analysis<sup>4</sup> was used to examine the relative significance of precipitation on streamflow, following which time trends were evaluated in the residual variation. The residual variation was plotted against time to determine if there was a time trend in the unexplained variation. Precipitation records from the Centralia climate station (Coop #451276) were used for this portion of the analysis. The general form of the regression equations used was:

$$Y = aX^b$$

**Equation 5.1-1**

Where: Y = Streamflow variable (cfs)

a and b = Regression constants

X = Precipitation variable at Centralia station (in.)

As in the preceding section the variables used to describe streamflow were mean annual flow and annual low flow at both locations. Mean annual precipitation at the Centralia station was the precipitation variable used to evaluate mean annual flow. Annual low flow was evaluated using an antecedent wetness index as the precipitation variable. The antecedent wetness index was derived using daily precipitation values from the Centralia climate station following the approach used by Lewis and others (2001). The underlying assumption of the antecedent wetness index is that precipitation that has occurred prior to time “t” influences the runoff efficiency at time “t”, and that this influence decays over time. Put another way, the runoff associated with today’s precipitation will be strongly influenced by yesterday’s precipitation, slightly less by precipitation from the day before yesterday, and so on. The antecedent wetness index was calculated as follows:

$$W_i = CW_{i-1} + P_i$$

**Equation 5.1-2**

Where: C = wetness constant

$W_i$  = wetness index on day i (in.)

$W_{i-1}$  = wetness index on day i-1 (in.)

$P_i$  = Precipitation on day i (in.)

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<sup>4</sup> Regression analysis is a statistical evaluation of a group of identifiable characteristics that together can predict the outcome of a specific event.

The value of the wetness constant in Equation 5.1-2 is the value that satisfies the relationship  $C^{\text{half-life}} = 0.5$ , where half-life is in days. The values of C used in Equation 5.1-2 were arrived at iteratively by trying several values for half-life (ranging from 7 to 161 days, in 7 day increments), solving for C, calculating  $W_i$  on the day of the annual low flows, and then solving Equation 5.1-1. The final value chosen for C was the value that gave the best solution (i.e., highest  $r^2$  value) to Equation 5.1-1.

Mean annual discharge at the Ohop Creek gage as a function of mean annual precipitation at the Centralia station is shown in Figure 5.1-13. Mean annual precipitation alone is a fair predictor ( $r^2 = 0.47$ ) of mean annual stream flow for this site (Table 5.1-9); however, there is considerable unexplained variation. Examination of the residual variation suggests a decreasing trend over time (Figure 5.1-14), which is significant at the  $p < 0.05$  using Kendall's rank-order correlation (Table 5.1-9).

**Table 5.1-9.** Regression results for equations predicting streamflow based on precipitation, and residual trend analysis results.

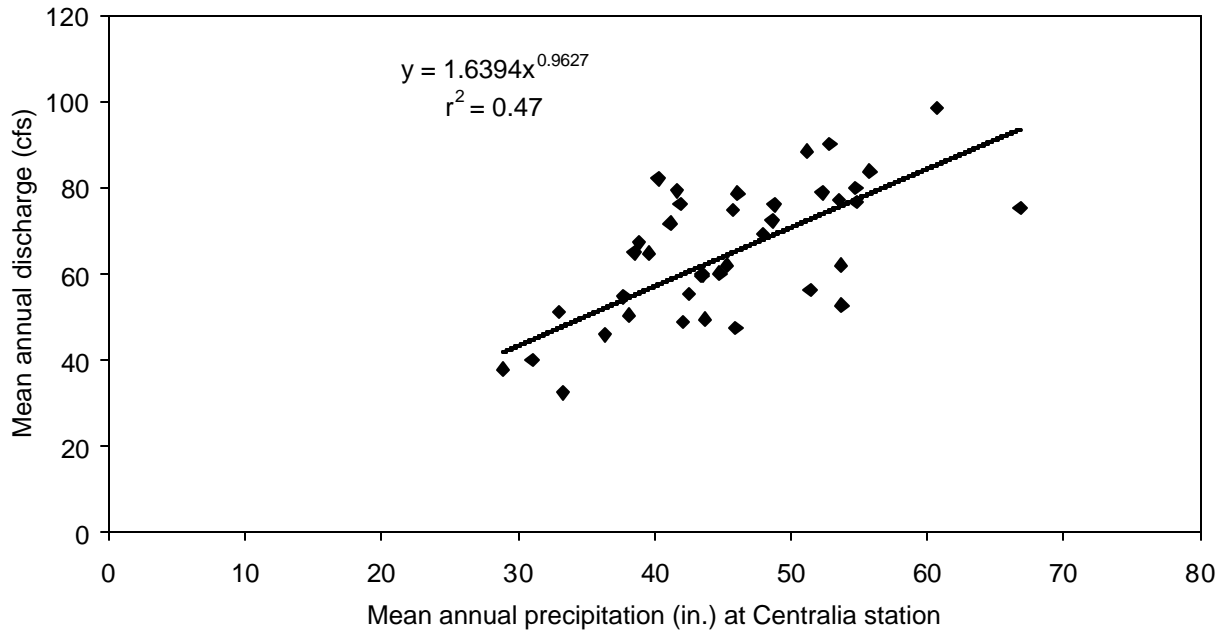
Location	Stream flow variable	Precipitation variable	n	[1] $r^2$	Wetness constant	Wetness ½ life (days)	Trend coefficient	Significance of trend
Ohop gage	Mean annual flow	Mean annual precipitation	39	0.47	n/a	n/a	-0.3009	0.0070
Combined mainstem	Mean annual flow	Mean annual precipitation	18	0.85	n/a	n/a	-0.0588	0.7332
Ohop gage	Annual low flow	Antecedent wetness index	34	0.20	0.98039061	35	0.0838	0.4860
Combined mainstem	Annual low flow	Antecedent wetness index	17	0.33	0.98905797	63	-0.1618	0.3648

Notes: [1] Adjusted for degrees of freedom

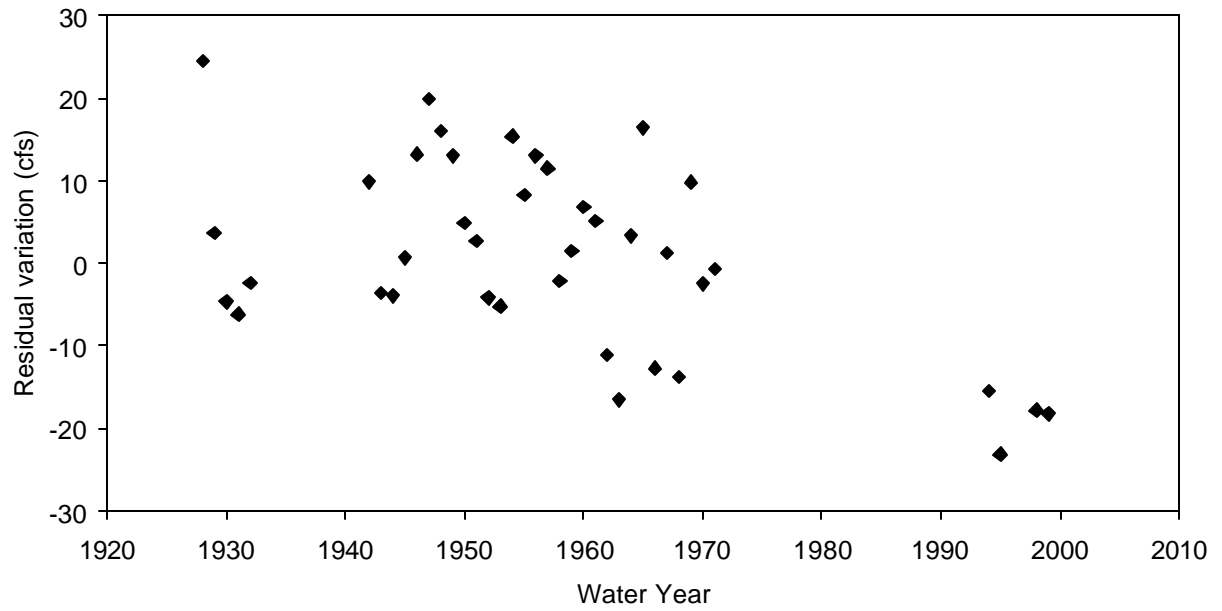
Figure 5.1-15 illustrates mean annual discharge for the combined mainstem location as a function of mean annual precipitation at the Centralia weather station. Mean annual precipitation alone is a surprisingly good predictor ( $r^2 = 0.85$ ). There are no significant time-related trends in the residual variation (Figure 5.1-16; Table 5.1-9).

Annual low flow discharge at the Ohop Creek gage as a function of precipitation index at the Centralia station is shown in Figure 5.1-17. Despite the effort expended to use the best possible index of antecedent moisture conditions, it appears that precipitation index is a poor predictor of annual low flow discharge ( $r^2 = 0.20$ ; Table 5.1-9, Figure 5.1-17). There are no significant time-related trends in the residual variation (Table 5.1-9, Figure 5.1-18). Annual low flow discharge at the combined mainstem location as a

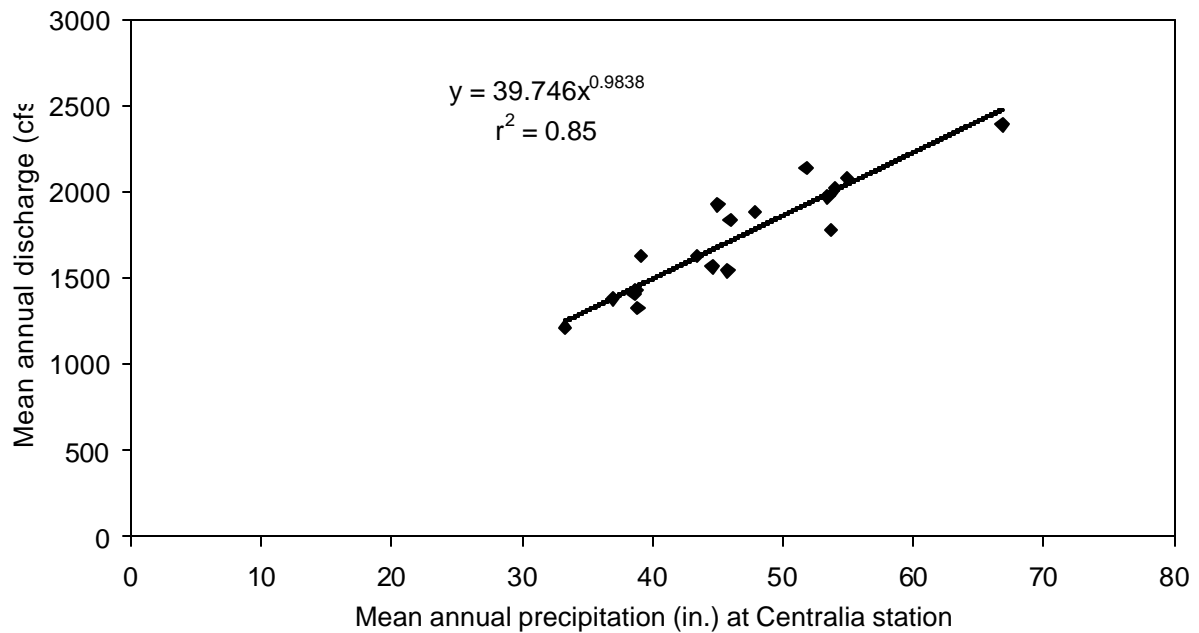
function of precipitation index at the Centralia station yielded only a slightly better relationship ( $r^2 = 0.33$ ; Figure 5.1-19), and there was no significant time-related trend in the residual variation (Figure 5.1-20).



**Figure 5.1-13.** Relationship between mean annual discharge at the Ohop Creek gage and mean annual precipitation at the Centralia station. Refer to Table 5.1-9 for regression results.

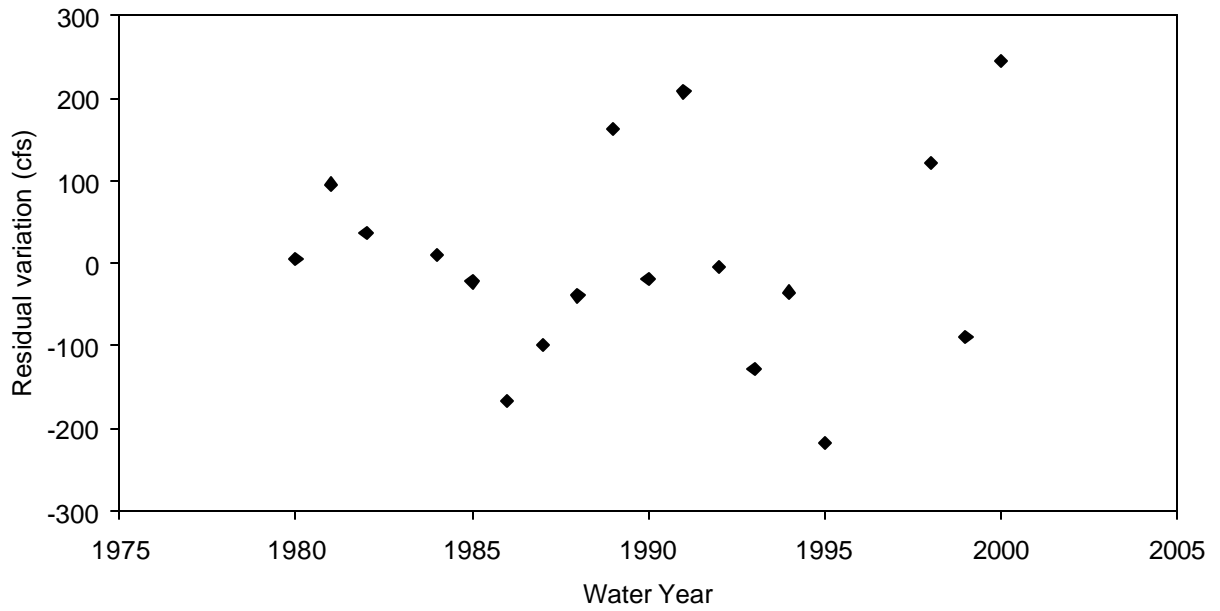


**Figure 5.1-14.** Temporal distribution of residual variation in relationship between mean annual discharge at the Ohop Creek gage and mean annual precipitation at the Centralia station. Refer to Table 5.1-9 for trend analysis results.

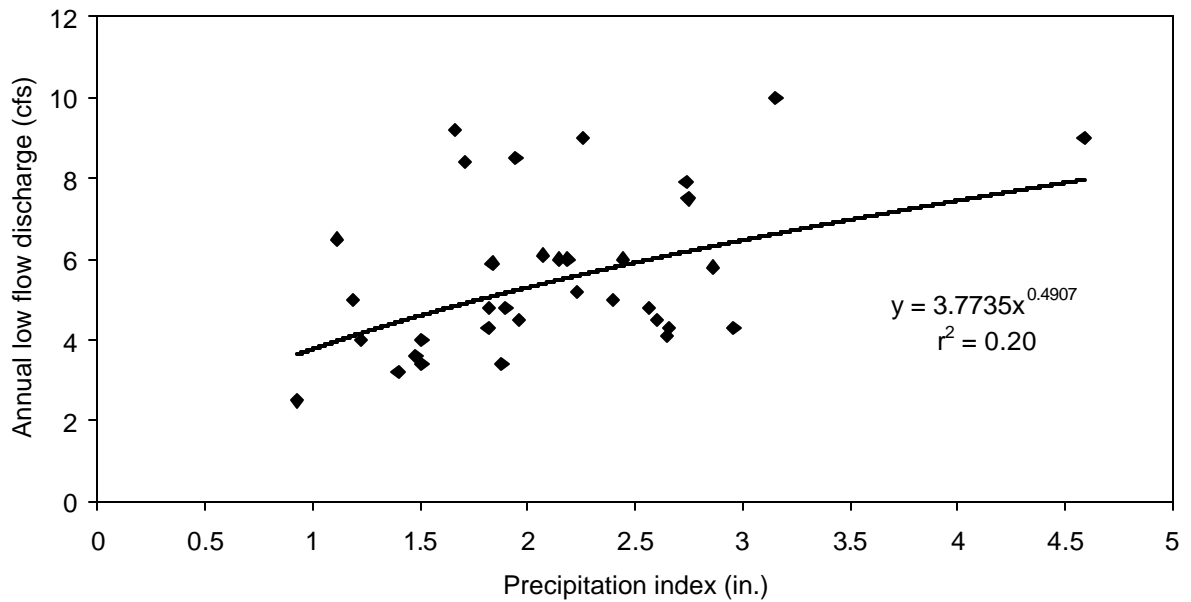


**Figure 5.1-15.** Relationship between mean annual discharge for the combined mainstem gages and mean annual precipitation at the Centralia station.

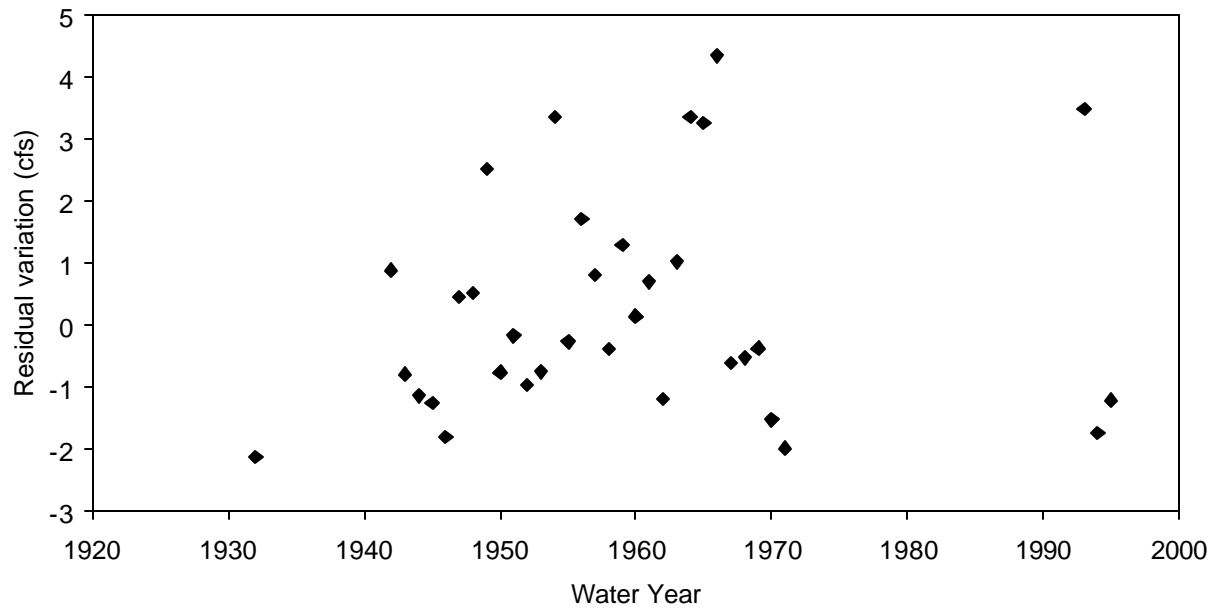




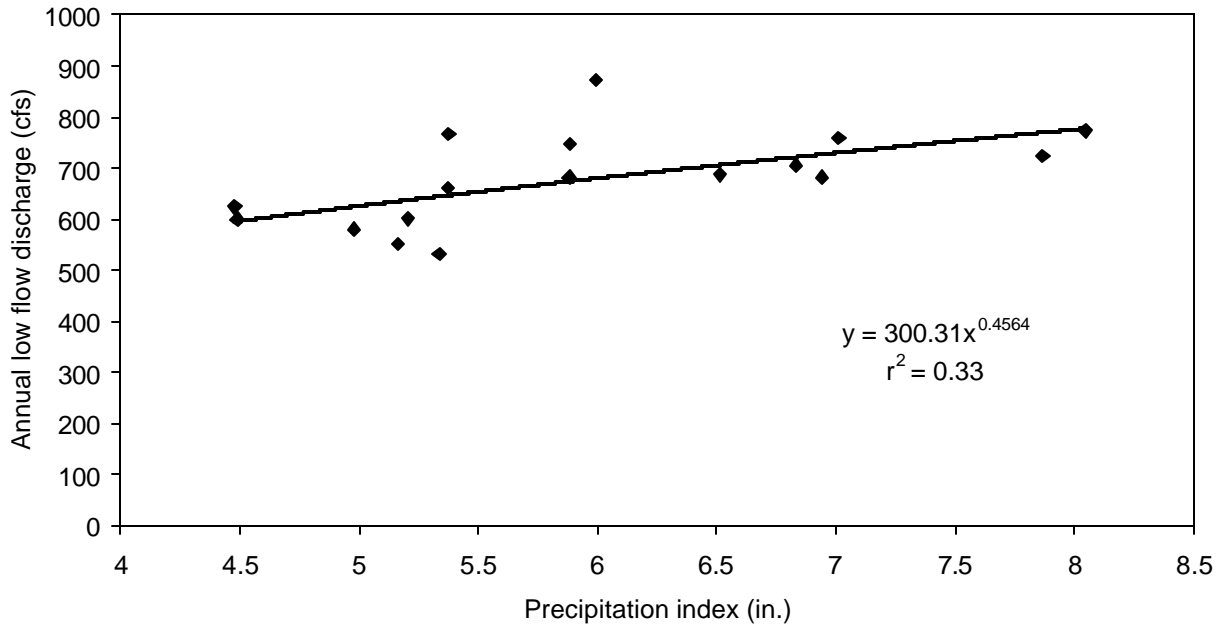
**Figure 5.1-16.** Temporal distribution of residual variation in relationship between mean annual discharge for the combined mainstem gages and mean annual precipitation at the Centralia station.



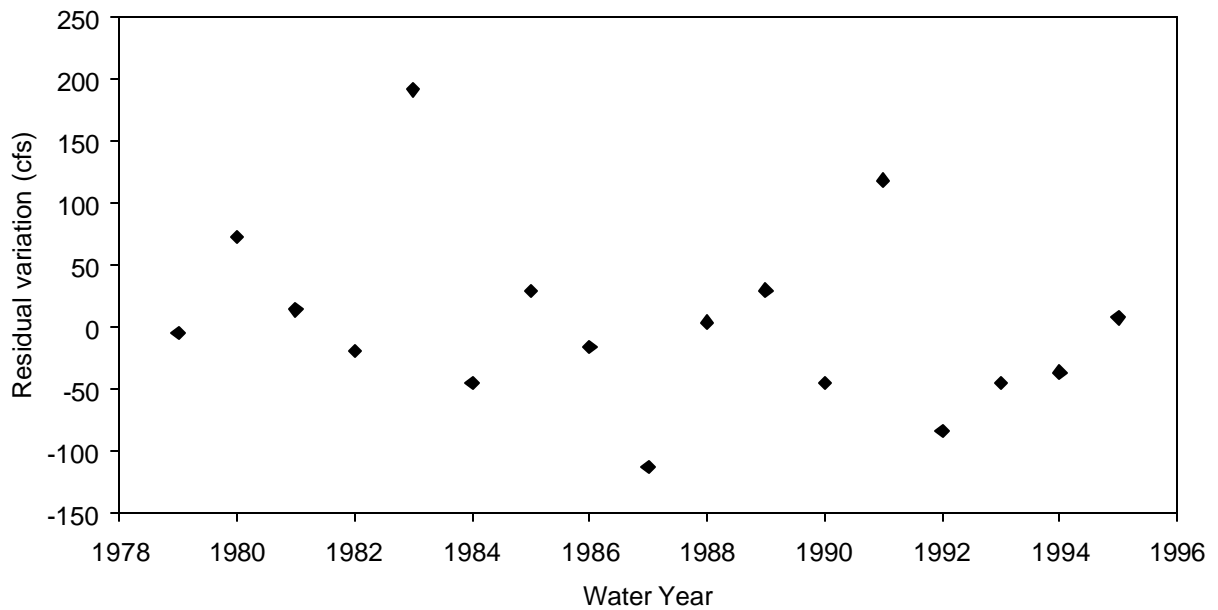
**Figure 5.1-17.** Relationship between annual low flow discharge at the Ohop Creek gage and precipitation index at the Centralia station. Refer to Table 5.1-9 for regression results.



**Figure 5.1-18.** Temporal distribution of residual variation in relationship between annual low flow discharge at the Ohop Creek gage and precipitation index at the Centralia station. Refer to Table 5.1-9 for trend analysis results



**Figure 5.1-19.** Relationship between annual low flow discharge at the combined mainstem location and precipitation index at the Centralia station. Refer to Table 5.1-9 for regression results.



**Figure 5.1-20.** Temporal distribution of residual variation in relationship between annual low flow discharge at the combined mainstem location and precipitation index at the Centralia station.

## **SUMMARY OF STREAM FLOW TREND ANALYSIS**

No significant trends over time were detected in the mean annual streamflow data at the two representative locations (i.e., Ohop Creek gage and for the combined flows of the Nisqually River and Centralia Canal) evaluated in this assessment. However, when precipitation was factored out, there was a significantly ( $p = 0.0070$ ) decreasing trend in mean annual streamflow at the Ohop Creek stream gage. This observed trend may be due to additional climatic variables not accounted for (e.g., air temperature, snowpack), may be due to land use impacts on water yield, or may be due to increases in consumptive water use.

Annual low flows occur primarily in the months of August and September at both the Ohop Creek gage and for the combined flows of the Nisqually River and Centralia Canal location. No significant trends over time were detected in annual low flows either in the streamflow data itself, or after factoring out the influence of precipitation.

Additional analyses at other gage locations, as well as more robust analyses at the representative sites above, is limited by the availability of long-term streamflow records. Given the short term nature of the data set, and the many years that would be required to obtain adequate data for a more robust analysis, the appropriate level II recommendation may be to undertake further hydrologic modeling to assess the effects of other climatic variables and land use activities.